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ENERGY AND EXERGY ANALYSIS OF DIESEL ENGINE RUN ON DIFFERENT SECOND GENERATION BIODIESELS

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ABSTRACT

The present work focuses on experimenting the functional efficacy of coconut biodiesel (CB), palm biodiesel (PB) and sunflower biodiesel (SB) transesterified from waste and fried cooking oils in a compression ignition engine. Analysis based on first and second laws of thermodynamics is done to understand the maximum possible performance of the engine and the associated irreversibility. The first law analysis helps in understanding that the energy distribution is dependent of the physiochemical properties of the fuel used. The heat energy input to the engine is higher in case of PB than CB, SB and diesel. But, the percentage of energy input converted to heat energy in terms of brake power is found to be the least for PB owing to its properties. The least percentage of heat is lost through cooling water in case of diesel which is 18 percent and higher in the case of SB which is 26 percent. The unaccounted losses are the highest in the case of diesel up to 43 percent and least in the case of SB up to 35 percent. Second law analysis concludes that the energy degradation is more in case of PB and least in the case of SB. The entropy is more in case of PB and least for CB and SB.

KEYWORDS: Experimenting the Functional Efficacy & Least Percentage of Heat is Lost

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Original Article

I. INTRODUCTION

The depleting fossil fuel sources are forcing the research community to search for alternative fuels that fit the conventional engines which do not demand any major modifications. Vegetable oils are the most promising alternative [Xiaohu Fan et al, 2009] because they are not only renewable, but also easily available [MertGulum et al, 2017, EkremBuyukkayya et al, 2010]. As far as the Indian economy is concerned, India is one of the largest producers of oilseeds in the world and also the second largest importer of edible oils following China [Suwen Pan et al, 2008]. Reportedly, the production of oilseeds counts to 20.87 million tons during the year 1999-2000 in India [Dr. Sarwade W.K et al, 2011] which contributes to about nine percent of the world oilseeds production [Louden D. L and Della Bitta, 2001]. Several domestic programs, trade reforms and steady economic growth have increased the imports by ten times in the following decade [Suwen Pan et al, 2008]. Several attempts using peanut, palm, linseed, soyabean, rapseed and coconut oils directly in diesel engines were made by different researchers in different corners of the world [Kiran Raj Bukkarapu et al, 2017a, S. Bari, 2004]. However, the results were not fruitful owing to their physiochemical properties which limited their usage. The transesterification process ,which turned a boon in reducing the high viscosities of vegetable oils helped many in the production of methyl esters viz.,. biodiesel [Kiran Raj Bukkarapu et al, 2017b]. In transesterification, triglycerides are allowed to react with ethanol/methanol in the presence of a catalyst like NaOH/KOH and are converted to mono-glycerides [Yusuf Ali et al, 1994], thus producing biodiesel.

Biodiesel is considered as the best fuel to replace conventional diesel as it is biodegradable, non toxic and renewable. [AmitSarin, 2002]. The increased imports and domestic production talk about the increased usage of edible oils in India, which are discarded after their usage. This signifies the availability of the used oils as fuels for automotive engines. Depending on the availability, different regions of India have preferred different oils. Reportedly, the southern and western parts of India prefer groundnut oil and sunflower oil while the eastern and northern parts prefer mustard seed and rapseed oil. However, certain regions in the southern part of India prefer coconut oil too. Hence, this work focuses on using used/waste cooking oils such as sunflower oil, palm oil and coconut oil as feedstock to produce biodiesels.

The viability of any new source of energy is indicated by determining the energy efficiency, which is a correlation between the quantity and quality of the energy [N. M. Al-Najem, 1992]. It is important to take into account both the concepts of energy and availability to have better utilization of the energy. This can be achieved by employing the first and second laws of thermodynamics. The first law of thermodynamics talks about the conservation of energy while the second law of thermodynamics about the degradation of energy introducing the concept of entropy. This approach is termed as exergy or availability analysis. Energy gets degraded during conversion and the responsible loses can be characterized by the concept of availability [Harilal S.S. and J. Y. Hitesh, 2012]. Energy is conserved while availability, which is the useful work that can be obtained before the system reaches equilibrium, gets destroyed in all the actual processes [Islam M.M, 2011]. Researchers have realized that the analysis based on first and second laws of thermodynamics is important as it helps in understanding the maximum possible performance of an engine running on any fuel and the associated irreversibility.Canakci.M and M. Hosoz have analyzed the performance of a diesel engine run on different biodiesel fuels and have observed that the tested biodiesels have the same energetic performance as diesel while the exegetic performance parameters follow similar trends with the corresponding energetic parameters [Canakci.M and M. Hosoz, 2006].

The present work focuses on conducting the energy and availability analysis of different biodiesels which would help in understanding the technical feasibility and functional efficacies of different second generation biodiesels used as alternatives for conventional diesel.

II. MATERIALS AND METHODOLOGY

1. Biodiesel Production

The used cooking oils were supplied by students' mess of VFSTR University. The acid values of these oils ranged between 0.92 and 1.64 g NaOH/kg. The biodiesel production from waste cooking oil involves pretreatment of feedstock followed by the transesterification reaction. Impurities in the feedstock, for example, solid impurities, food particles remains, moisture content of nearly 5 percent are removed by pre-treatment of the feedstock. Elimination of these impurities is necessary as they can have a negative impact on the transesterification process. Any impurities such as suspended food remains, and solid impurities are removed in primary filtering, which is done using a basic cloth filter. A filter paper is used for secondary filtering. The feedstock is heated to 60°C which makes it less viscous and this facilitates in completing the filtering in a shorter duration. Water soluble impurities are removed by water washing. Finally, the feedstock is heated to 105°C to remove water completely. Their free fatty acid content is found to be between 1.02 and 1.35 g NaOH/kg of oil. Therefore, single-stage transesterification is opted to produce biodiesel. Methanol was added to coconut oil, preheated to 60°C, in 6:1 ratio with 1 percent of sodium hydroxide as catalyst and stirred at a speed of 500 RPM for 6 h. The products of transesterification are allowed to settle in a gravity separator for 8 h and glycerol is removed. After formulating this acceptable strategy for producing biodiesel, the same method is adopted for all the oils.

The biodiesel thus produced are subjected to water washing for the removal of dissolved methanol and NaOH. The water content in the biodiesel is removed by heating them to 105°C. The biodiesel yield from used coconut oil is termed as coconut biodiesel (CB), used palm oil is termed as Palm biodiesel (PB) and from used sunflower oil is termed as sunflower biodiesel (SB).

2. Physiochemical Properties

Kinematic viscosity is measured using Ostwald viscometer, according to ASTM D-445 where it is limited to 1.9-6.0 mm^2/s at 40°C. There is no any ASTM method described or limit for density measurement. Density of the samples is determined using a 25ml pycnometer at 40°C and calorific value is measured as specified by ASTM, in Fuels lab of VFSTR University. The uncertainty for all the measurements is between 0.5 percent - 1.5 percent for three separate determinations.

3. Test Set Up

A constant speed and variable load test is conducted in asingle cylinder four stroke computerized direct injection diesel engine. The specifications of the engine are tabulated as Table 1. Combustion analysis and data sampling is done using IC engine soft_9.0. The test engine is equipped with an eddy current dynamometer. The crank angle measurements are made using Kubler make 8.3700.1321.0360 crank angle sensor. In-cylinder pressure measurements are communicated using IKA SL-1 pressure transmitter whose pressure ranges to 25MPa. The experiments were conducted at a constant speed of 1500 rpm for different loads using diesel and methyl esters derived from used coconut, palm and sunflower oils.

Table 1 Specifications of the Test Engine

S.No	Specifications of the Test Engine	
1.	Engine type	Four stroke Direct injection computerized diesel engine
2.	Number of cylinders	1 no.
3.	Bore	87.5 mm
4.	Stroke	110 mm
5.	Displacement	0.661 ltr
6.	Compression ratio	17.5:1
7.	Max. torque	33 Nm at full load
8.	Max. power	5.2 kW at 1500 rpm
9.	Injection timing	23 deg CA bTDC

4. Analysis Based on First Law of Thermodynamics

Only a certain portion of heat input given to the engine gets converted to heat equivalent to brake power. The remaining portion of heat energy is carried away by cooling water, exhaust gases and the unaccounted loses which include radiation, friction, fluid flow losses, combustion losses, mixing losses, intake and exhaust throttling losses etc.,. Therefore, it is important to analyze the different ways in which energy input to the engine is lost which is done on the basis of first law of thermodynamics. Understanding the variation of these different forms of energies with the load would facilitate in improving the engine performance.

Heat input (Q-Input) to an engine is a product of the fuel flow rate (m_f) and its lower calorific value (LCV). It is given by the following equation (1)

$$Q_{input} = m_f * LCV \tag{1}$$

The heat energy converted to shaft power is calculated using equation (2). The heat energy carried away by cooling water, exhaust gases and the unaccounted loses are calculated using equations (3), (4) and (5) respectively.

$$Q_{BP} = \frac{2\pi NT}{60000} \tag{2}$$

$$Q_{CW} = m_w * C_{p,\,w} * (T_{co}\text{-}T_{ci}) \tag{3}$$

$$Q_{EXH} = m_{exh} * C_{p,\,exh} * (T_{exh}\text{-}T_o) \tag{4}$$

$$Q_{UAL} = Q_{input} - (Q_{BP} + Q_{CW} + Q_{EXH}) \tag{5}$$

where N is speed of the engine in rpm, T is torque generated in N-m, m_w is the mass flow rate of cooling water to the engine in kg/h, $C_{p,\,w}$ and $C_{p,\,exh}$ are the specific heats of cooling water and exhaust gases in kg/kW-h, T_{ci}, $T_{co,}$ T_{exh} and T_o are the inlet and outlet temperatures of the cooling water, exhaust temperature and ambient temperature respectively in Kelvin. It is important to note that the mass flow rate of exhaust (m_{exh})is equated to sum of the mass flow rates of fuel and air.

5. Analysis Based On Second Law Of Thermodynamics

The availability transferred to cooling water, exhaust gases and the availability lost due to unaccounted loses are actually from the availability present in the input to the diesel engine. These availability transfers are determined using second law of thermodynamics. The chemical availability of fuels is calculated using [8] equation (6). The availability transferred to cooling water, exhaust gases and the availability lost due to unaccounted loses are determined using equations (7), (8), (9) and (10)

$$A_{input} = 1.0338 * Q_{input} \tag{6}$$

$$A_{BP} = Q_{BP} \tag{7}$$

$$A_{CW} = Q_{CW} - T_o(m_w * C_{p,w} * \ln\frac{Tco}{Tci}) \tag{8}$$

$$A_{EXH} = Q_{EXH} + m_{exh} * T_o * [C_p \ln(\frac{To}{Texh}) - R_{exh} \ln(\frac{Po}{Pexh})] \tag{9}$$

$$A_{UAL} = A_{input} - (A_{BP} + A_{CW} + A_{EXH}) \tag{10}$$

whereP_{exh} is calculated by assuming its molecular weight as 28.75 g/mol and characteristic gas constant (R_{exh}) as 0.287 kJ/kgK.The exergy efficiency which is also known as second law efficiency is given by equation (11)

$$\eta_{II} = \frac{Ainput - AUAL}{Ainput} * 100\ \% \tag{11}$$

The entropy generated is calculated using the following equation (12)

$$S = \frac{AUAL}{Texh} \tag{12}$$

III. RESULTS AND DISCUSSIONS

The results pertaining to performance and combustion characteristics of Coconut biodiesel (CB), palm biodiesel (PB), sunflower biodiesel (SB) in comparison to diesel are presented and discussed here.

1. Physiochemical Properties

Waste coconut oil, waste palm oil and waste sunflower oil supplied by the university mess are used in processing the biodiesels by transesterification and are characterized. Table 2 demonstrates the physiochemical properties of the processed methyl esters.

Table 2: Physiochemical Properties of the Processed Methyl Esters

S. No	Type of fuel	Kinematic viscosity at 40°C (mm^2/s)	Density at 40°C (kg/m^3)	Calorific value (kJ/kg)
1.	Coconut biodiesel	2.65	823	35000
2.	Palm biodiesel	4.60	850	37880
3.	Sunflower biodiesel	4.90	829	37080
4.	Diesel	2.60	830	42000

It is worthwhile to note that CB exhibits least viscosity that is close to diesel, with least energy content among all. On the other hand, CB also has the least density among all. SB is as dense as diesel at 40°C but has lesser energy content relative to diesel. It also has the highest viscosity among all which is almost twice that of diesel. PBis the densest among all, with higher energy content among the aforementioned biodiesel, but still lesser than that of diesel. Viscosity is a fuel property that influences spray atomization characteristics. Heating value of any fuel talks about the energy content and density about the mass of fuel consumed. Therefore, the varying properties of these different methyl esters would obviously have their influence on their combustion, emission and performance characteristics of the engine.

2. Thermodynamic Analysis

The results pertaining to energy analysis of coconut biodiesel (CB), palm biodiesel (PB) and sunflower biodiesel (SB) in comparison with diesel are presented and discussed in this section.

2.1 Analysis Based on First Law of Thermodynamics

It is important to analyze the different ways in which energy input to the engine is lost. Understanding the variation of these different forms of energies with the load would facilitate in improving the engine performance. Heat input to an engine is a product of the fuel flow rate and its calorific value. As fuel is injected on a volume basis in a diesel engine, the greater mass of the fuel would be injected if it is denser. PB is the densest fuel among the three biodiesels and the neat diesel, as shown in Table 2. Therefore, it is obvious that the mass flow rate of PB would be higher than the other fuels. With the highest fuel flow rate and highest calorific value among all the biodiesels, the heat energy input to the engine is more in case of PB among all the biodiesels for same load. Figure 1a shows the heat input to engine at different loads. However, despite of highest heat input given to the engine in case of PB, it could not yield highest power output. It is important to note that the viscosity of a fool plays a vital role in energy conversion as it influences the spray characteristics. Though the heat energy input to the engine is higher in case of PB than CB, SB and diesel, the percentage of energy input converted to heat energy in terms of brake power is found to be the least for PB. The obvious reason would be its high viscosity which results in poor atomization and thus poor combustion. It is observed from Figure 1b that the heat energy converted to work output is similar for CB, SB and diesel up to 30 percent load. Interestingly, the energy converted to brake power is found to be slightly higher in case of CB and SB than diesel, at higher loads, which can be attributed to the physiochemical properties of the biodiesels. Hence, it can be concluded that using CB and SB is advantageous in terms of the energy conversion, at the expense of increased consumption when compared to diesel. Figure 1c shows the heat carried away by cooling water at different loads for different fuels. It shows that the energy lost varies with the load. It is clear that the cooling water carries away less percentage of heat energy with it, in case of diesel than

biodiesel. At higher loads, almost the same percentage of energy is taken away from the cooling water for all the biodiesel. The heat taken away by cooling water varies from 20 percent to 30 percent in case of diesel, 22 percent to 38 percent in case of CB, 23 percent to 33 percent in case of PB and 25 percent to 50 percent in case of SB. As shown in Figure 1d, more percentage of energy is lost due to exhaust gases in case of diesel than biodiesels and it varies from 10 percent to 14 percent. It can also be observed that almost the same percentage of energy is taken away by the exhaust gases in case of all the biodiesels at all the loads, varying from 9 percent to 13 percent. Figure 1e indicates that the unaccounted losses are highest in case of diesel and least in the case of SB of all the ladies.

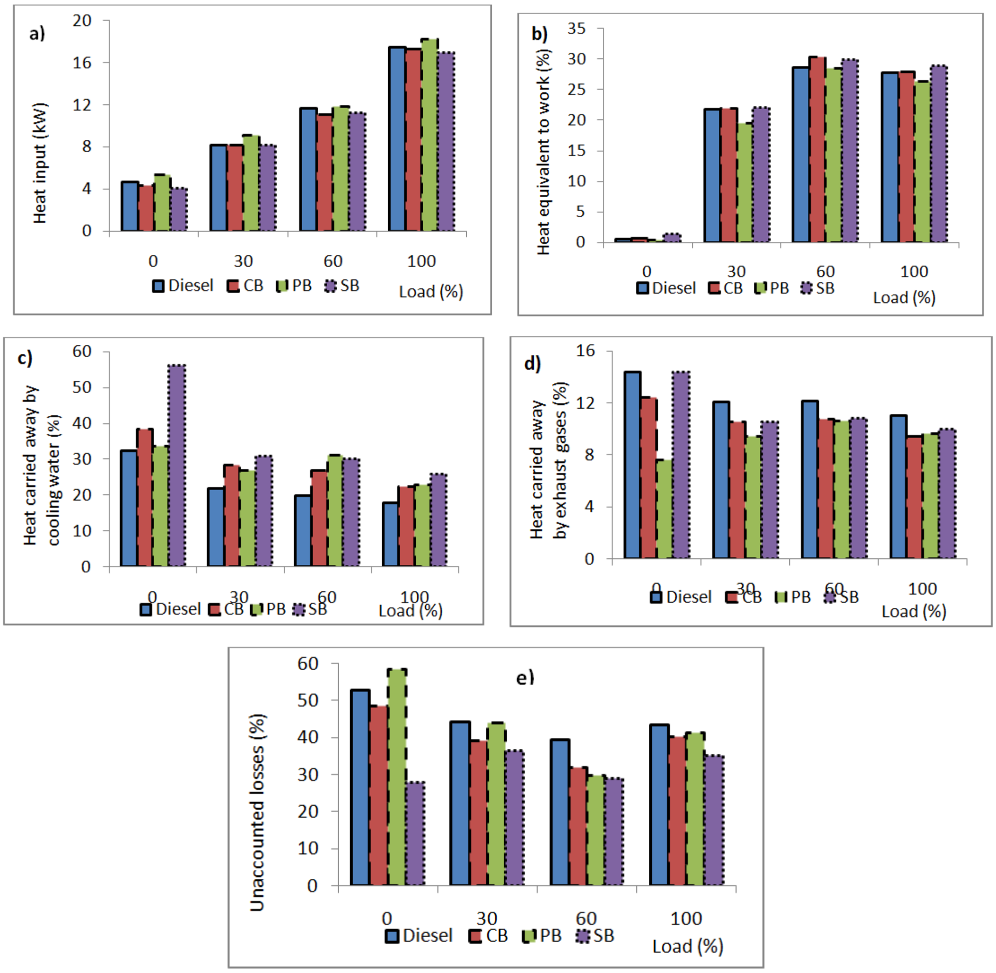


Figure 1: Heat Distribution in Case of All the Samples at Different Loads

Figure 2a, Figure 2b, Figure 2c and Figure 2d show the energy distributions in case of different fuels at near full load. Apparently, the energy converted to brake power is found to be nearly 28 percent for diesel, CB and SB. Least percentage of heat is lost through cooling water in case of diesel, which is 18 percent and higher in the case of SB which is 26 percent. The unaccounted losses are highest in case of diesel up to 43 percent and least in case of SB up to 35 percent. This clearly signifies that attempts to reduce heat carried away by cooling water further more in case of SB can pave the way in making it a better alternative to diesel.

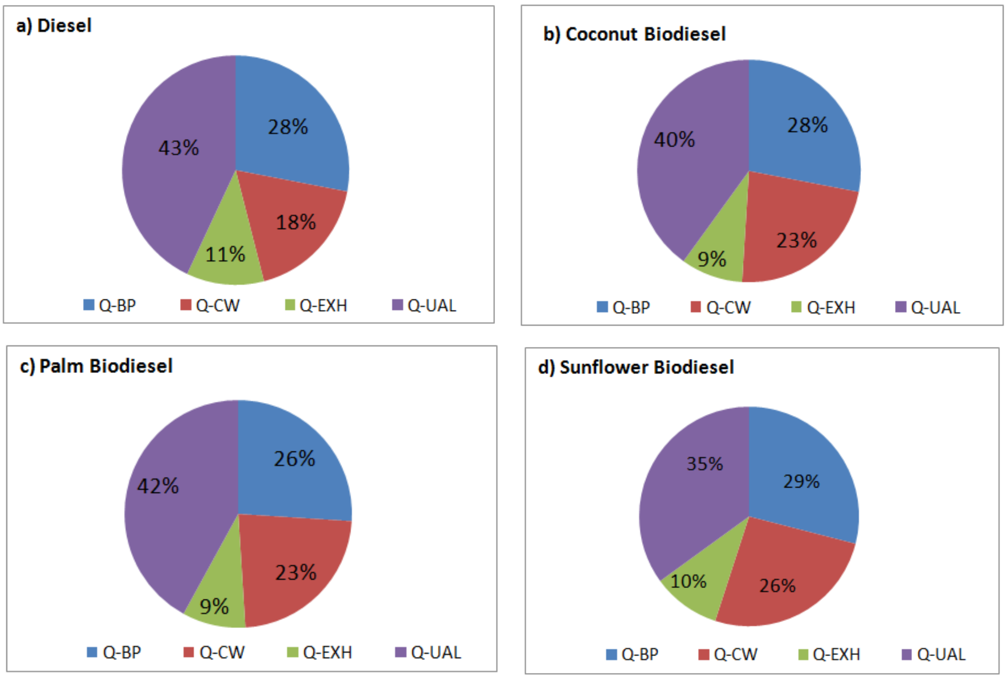
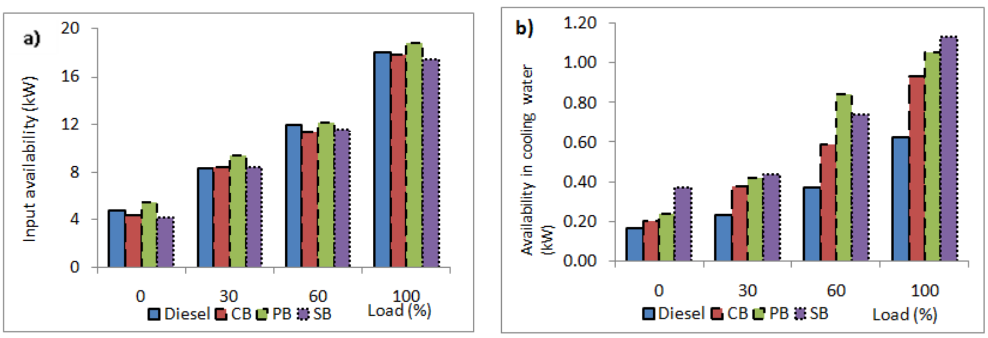


Figure 2: Heat Distribution for All the Fuels at Near Full Load

2.2 Analysis Based on Second Law of Thermodynamics

At any load, it is found that the available heat energy is higher for PB followed by diesel, CB and SB, as shown in Figure 3a. The available input energy is almost same for both CB and SB. This trend is in accordance with the heat energy input to the engine. Figure 3b represents the availability transferred to cooling water at different loads. It can be observed that the energy available in cooling water is least in case of diesel and highest in case of SB. As shown in Figure 3c, the energy available in exhaust gases is more in diesel than biodiesels at any load. Figure 3d represents the availability lost due to unaccounted loses at different loads. It is found that the availability lost is the maximum for PB at any load, followed by diesel, CB and SB. Figure 4 represents the variation of second law efficiency with load. It clearly indicates that the energy degradation is more in case of PB and least in case of SB. With the increasing load the exergy efficiency is found to increase up to 60 percent and then settle down till full load. However, the physiochemical properties of CB such as better viscosity and density seem to contribute for an exergy efficiency similar to diesel, despite of its lesser calorific value. Figure 5 depicts that the entropy generated increases with the load. At any load, the entropy is found to highest for PB than others. It is found to be lower than diesel for CB and SB at all the loads and this observation promotes the functional efficacy of CB and SB as fuels in engines, replacing diesel.



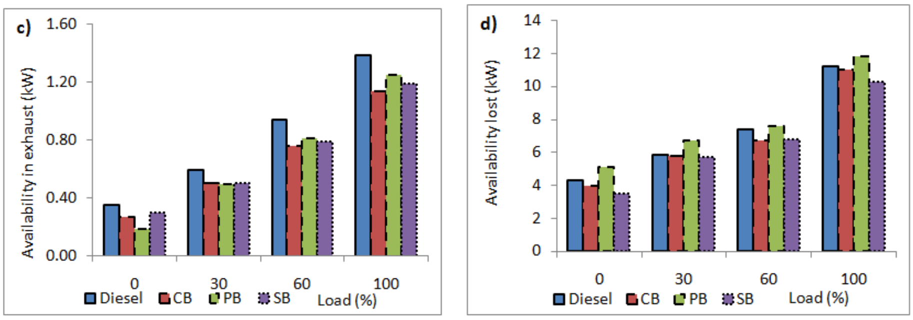


Figure 3: Availability in Case of all the Samples at Different Loads

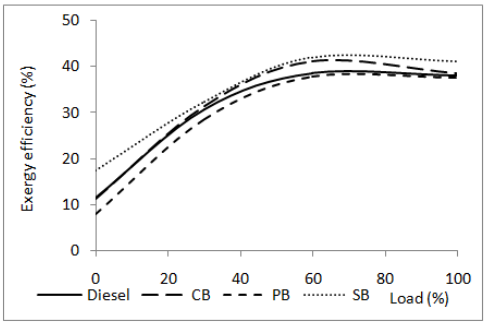


Figure 4 Variation of Second Law Efficiency with Load

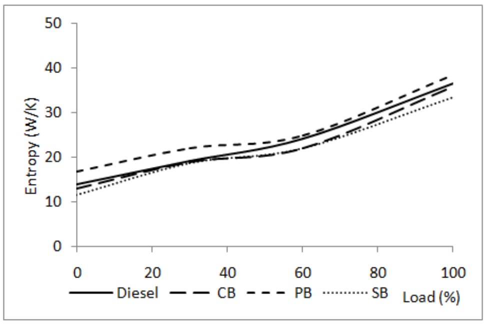


Figure 5: Entropy Versus Load

IV. CONCLUSIONS

The first law analysis helps in understanding that the energy distribution is a dependent of the physiochemical properties of the fuel used. The heat energy input to the engine is higher in case of PB than CB, SB and diesel. But, the percentage of energy input converted to heat energy in terms of brake power is found to be the least for PB owing to its properties. The least percentage of heat is lost through cooling water in case of diesel which is 18 percent and highest in case of SB which is 26 percent. The unaccounted losses are highest in case of diesel up to 43 percent and least in case of SB up to 35 percent. Second law analysis concludes that the energy degradation is more in case of PB and least in case of SB. The entropy is more in case of PB and least for CB and SB. From this it can be concluded that using PB is not so advantageous. However, employing effective ways of heat recovery systems could help us in utilizing the energy properly.

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